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TECHNICAL BULLETIN No. 919 • August 1946

VARIABILITY OF CERTAIN SEED, SEEDLING, AND YOUNG-PLANT CHARACTERS OF GUAYULE

By

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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Variability of Certain Seed, Seedling, and Young-Plant Characters of Guayule[1]

By Walter T. Federer[2]

Formerly *associate geneticist, Special Guayule Research Project, Bureau of Plan Industry, Soils, and Agricultural Engineering, Agricultural Research Administration*

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Essential to a pure-seed program and to the improvement of rubber yield in guayule (*Parthenium argentatum* A. Gray) is the knowledge of the genetic variability within and among strains. Several seed, seedling, and young-plant characters of guayule were studied to obtain information about (1) the relative interstrain and intrastrain variability of a group of plant characters pertinent to the yield of rubber, (2) the relation between plant characters, (3) the relative merits of strains as parents in a breeding program, and (4) the possi-

[1] Submitted for publication March 28, 1946.

[2] For their helpful suggestions and criticisms, the writer extends his thanks to G. W. Snedecor and P. G. Homeyer, Statistical Laboratory, Iowa State College, Ames, Iowa; to members of the plant-breeding and genetics section of the Special Guayule Research Project; and to the others who reviewed this bulletin. The commercial strains (varieties) and the other strains used in these studies were developed by W. B. McCallum, formerly employed by the Intercontinental Rubber Co. and now with the Emergency Rubber Project (U. S. Forest Service).

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bilities for improvement by selection. Furthermore, a study of irrigated field plantings of the commercial strains at Salinas, Calif., yielded data on the production of rubber and the growth of 1-year-old guayule under similar conditions.

MATERIALS AND METHODS

Commercial-Strain Test

In 1942 the guayule nurseries were seeded to 7 guayule strains (109, 130, 405, 406, 407, 416, and 593) which were being grown for commercial field plantings. Young plants were obtained from the nurseries and culled; the resulting progenies were transplanted to the experimental area in April 1943. The design of the experiment was a randomized split-plot design composed of 7 strains and 3 years of harvest in 9 replicates. The strain plots were employed as a split-plot feature of the year of harvest. Thus, there were 27 replicates for strains. The spacing was 28 inches between rows and 20 inches within rows. The split-plot size was approximately 1/40 of an acre.

As planned, the whole plots were to be harvested in the winters of 1944–45, 1945–46, and 1946–47. To obtain information about different plant characters on 1-year-old guayule (winter of 1943–44), 2 plants were harvested from each plot. The plants to be harvested were selected at random except for the restriction that they be surrounded by a full stand, as the stand over the entire experiment was 79 percent of a full one. This restriction was employed to avoid the influence that extra area, caused by missing plants, might have on the characters studied. This gave a sample of 54 plants for each entry, or a total of 378 for the 7 commercial strains.

Thirteen characters were recorded for most of the plants. In some cases the character was recorded on less than 54 plants because fewer plants were considered sufficient to give the information desired. The characters are (1) type of plant, (2) plant height, (3) plant spread, (4) circumference of the crown below the lowest branch, (5) green weight of plants, (6) oven-dry weight of plants without leaves, (7) oven-dry weight of leaves, (8) rubber content (percent on a dry-weight basis), (9) resin content (percent on a dry-weight basis), (10) diameter of branch sample, (11) diameter of wood in branch, (12) rubber content of branch (percent on a dry-weight basis), and (13) resin content of branch (percent on a dry-weight basis). Weight of rubber per plant equals the product of the percentage of rubber in the plant and the dry weight of shrub. The oven-dry weight of the plant minus the leaves is referred to as shrub weight. The proportion of wood in the branch is the quotient of the diameter of the wood divided by the diameter of the branch.

In order to determine how the various plant characters are related, correlation and regression coefficients (see table 4) were calculated as possible bases for predicting rubber yields and for possible genetic interpretations in inheritance.

As the first step in eliminating undesirable types 1,479 open-pollinated, individual-plant selections of the largest plants from the 7 commercial strains were made. Most of these were from 593 and 407, as they survived the best after transplanting and had the best general appearance at the end of the first growing season. Time and percentage of emergence and uniformity of type were determined for these selections. The selections of each of the 7 strains were grouped together in 7 individual experiments insofar as possible in 3 randomized complete blocks with 100 seeds per plot. An eighth experiment in the same design consisted of miscellaneous selections of which there were 8 aberrants, 21 offtypes, 51 normals, and strain 4263.[3]

Beginning the fourth day after planting counts on emergence were made every second day until the eighteenth day for the experiments on the 109, 130, 405, 406, 416, and miscellaneous selections and until the twentieth day on the selections of 593; a final count was made 1 week later. Daily counts were made on the selections of 407, beginning the fifth day and continuing until the eighteenth; a final count was made 1 week later. The classification of aberrants and offtypes was made when the plants were 3 to 4 months old.

Strain Test

The strain test represents the progeny of the seed collected in 1942 from the 7 entries in the commercial-strain test and from 35 of the more promising other strains of guayule developed by W. B. McCallum. In this experiment no plants were discarded or culled as done in commercial plantings and in the commercial-strain test. Seeds of the strains were planted in the Capitola, Calif., greenhouse in February 1943, and the seedlings were transplanted to the experimental area at Salinas, Calif., in June 1943 in a randomized complete-block design. The randomization was the same in the greenhouse and the field. Two of the strains, 42441 and 42468, were included twice. This gave 44 entries, which were planted in 20 randomized complete blocks. However, strain 42476 was included in only the first 10 replicates and strain 42477 in only the first 8. Strain 42478 was substituted for 42476 in the last 10 replicates and 42471 for 42477 in the last 12. The individual-plot size was 2 rows by 6 plants. The spacing was 3 feet between plants and 4 feet between rows. The designations used by W. B. McCallum (see table 8) are included, but the strains are discussed under strain, or accession, numbers. Strains marked "commercial" were obtained from the supply of seed used for large-scale nursery plantings. Even though similarities in previous designations existed, seed collections were given different accession numbers in the test.

Bergner[4] and Stebbins[5] determined the chromosome number for some plants of each of the strains and classified them into 2 chromosome groups, 54± and 72±. Bergner[4] and Stebbins and Kodani (*8*)[6] counted 108± chromosomes in some plants classified as aberrants in 72±-chromosome strains.

The characters recorded on the entries in the strain test were plant height and spread, percentage of aberrants, and time of flowering.

[3] A 54±-chromosome selection made by LeRoy Powers in Durango, Mexico. It was used as a check because of its uniformity in Powers' experiments. (Unpublished data of Special Guayule Research Project.)

[4] Bergner, A. D. Unpublished data of Special Guayule Research Project.

[5] Stebbins, G. L.; Jr. Correspondence.

[6] Italic numbers in parentheses refer to Literature Cited, p. 25.

In addition emergence data for four seed treatments were obtained on a mass selection of the better normal plants of each strain. The percentage of aberrants was computed on the basis of a full stand, although the final stand was 98 percent.

DATA FROM COMMERCIAL-STRAIN TEST

YIELD DATA FOR ALL PHENOTYPES

Yield of rubber per plant depends on the rubber content and the shrub weight, and yield per acre on the stand and the yield per plant. The results of Kelley, Hunter, and Hobbs (*4*) showed that transplanting losses can be largely eliminated by proper nursery care of the seedlings. Differences in stand among strains may also be due to genetic make-up. In light of the results of Kelley, Hunter, and Hobbs and the fact that nursery care of the seedlings was confounded with strain differences, acre yield of rubber computed for a full stand gave the best comparison of strain differences. By use of the analysis-of-variance technique (*3*, *7*) nonsignificant F values for strain differences were obtained for dry weight of leaves, shrub weight, and resin content per plant; a significant F value was obtained for weight of rubber per plant and a highly significant one for rubber content per plant. The means and standard errors of a difference between two means (table 1) were computed for each of the commercial strains. Although strains 405 and 407 were significantly lower than 109, 130, 406, and 593 in rubber content, the larger shrub weight per plant compensated enough to produce about the same yield. In contrast 416 produced the least rubber, as it was low in both rubber content and shrub weight. Of the seven commercial strains 109 and 593 produced the most rubber per acre and 416 the least.

The variation for the different plant characters in table 1 was rather large, as shown by the various coefficients of variation. The commercial strains were uniform for contents of rubber and resin. However, leaf, shrub, and rubber weights per plant were quite variable. From this it is evident that shrub weights must be more accurately measured than rubber contents. The number of plants required for a specified degree of precision was studied by Federer (*2*).

TABLE 1.—*Means, standard errors of a difference, and coefficients of variation for rubber percentage and yield, shrub weight, resin percentage, and leaf weight of 7 commercial strains of guayule (dry-weight basis)*

[Leaf weights based on 10 determinations for each strain; all others based on 54 each]

Commercial strain	Per plant					Per acre
	Leaf weight	Resin content	Rubber content	Shrub weight	Rubber yield	Rubber yield
	Grams	*Percent*	*Percent*	*Grams*	*Grams*	*Pounds*
109	32.64	5.89	6.46	91.39	5.82	143.7
130	29.63	5.78	6.36	89.16	5.64	139.3
405	25.84	5.75	5.77	95.16	5.31	131.1
406	19.81	5.74	6.19	93.58	5.72	141.2
407	24.81	5.98	5.44	96.87	5.23	129.1
416	21.55	5.92	5.45	83.11	4.35	107.4
593	26.15	5.82	6.80	87.31	5.81	143.5
Mean	25.78	5.84	6.07	90.94	5.41	133.6
Standard error of a difference between 2 means	6.64	.10	.14	8.37	.47	
Coefficient of variation (percent)	41	6	9	34	32	

Yield Data for Different Phenotypes

The plants of each strain were divided into four phenotypically different types, or classifications: Normals, offtypes, slow growers, and aberrants (table 2). The largest group in a strain was classified as normal. These plants were uniform with respect to flower type,

Table 2.—*Means and standard errors (dry-weight basis) for rubber percentage and yield, shrub weight, and resin percentage of the various phenotypes of 7 commercial strains of guayule*

Commercial strain and phenotype	Plants		Per plant				Per acre
			Resin content	Rubber content	Shrub weight	Rubber yield	Rubber yield
	Number	*Percent*	*Percent*	*Percent*	*Grams*	*Grams*	*Pounds*
109:							
Normals	27	50.0	5.82±0.11	6.81±0.03	115.51± 6.47	7.79±0.38	192.4
Offtypes	15	27.8	5.85± .02	5.62± .17	99.89± 8.00	5.52± .42	136.3
Aberrants	2	3.7	5.39±1.42	5.34±1.06	26.40± 7.70	1.33± .12	32.8
Slow growers	10	18.5	6.23± .23	7.02± .32	26.48± 5.64	1.84± .38	45.4
All phenotypes	54	100	5.89	6.46	91.39	5.82	143.7
130:							
Normals	48	88.9	5.81± .03	6.36± .02	96.49± 3.88	6.10± .24	150.6
Offtypes	1	1.9	5.48	6.39	56.20	3.59	88.7
Aberrants	1	1.9	5.74	5.61	30.40	1.71	42.2
Slow growers	4	7.4	5.61± .13	6.46± .36	24.12± 6.15	1.62± .49	40.0
All phenotypes	54	100	5.78	6.36	89.16	5.64	139.3
405:							
Normals	30	55.6	5.77± .12	5.47± .13	129.31± 5.95	7.05± .34	174.1
Offtypes	12	22.2	5.69± .22	5.85± .34	82.92± 8.44	4.86± .61	120.0
Aberrants	2	3.7	5.35± .50	6.52± .37	19.05± 4.34	1.26± .35	31.1
Slow growers	10	18.5	5.83± .23	6.39± .12	22.60± 5.56	1.44± .36	35.6
All phenotypes	54	100	5.75	5.77	95.16	5.31	131.1
406:							
Normals	50	92.6	5.73± .03	6.18± .10	98.84± 3.69	6.04± .22	149.2
Offtypes	1	1.9	6.46	6.80	40.40	2.75	67.9
Aberrants	1	1.9	5.87	5.59	20.50	1.15	28.4
Slow growers	2	3.7	5.58± .01	6.62± .20	25.10± .30	1.66± .03	41.0
All phenotypes	54	100	5.74	6.19	93.58	5.72	141.2
407:							
Normals	38	70.4	6.00± .02	5.41± .11	113.47± 4.76	6.09± .24	150.4
Offtypes	11	20.4	6.02± .14	5.47± .21	70.42± 7.25	3.83± .40	94.6
Aberrants	0	0					
Slow growers	5	9.3	5.70± .33	5.54± .51	28.90±11.09	1.74± .73	43.0
All phenotypes	54	100	5.98	5.44	96.87	5.23	129.1
416:							
Normals	30	55.6	6.04± .02	5.30± .03	108.70± 5.10	5.75± .28	142.0
Offtypes	7	13.0	5.79± .27	4.97± .66	100.69±14.90	4.59± .69	113.3
Aberrants	2	3.7	5.26± .48	5.84± .69	35.10±17.60	1.92± .78	47.4
Slow growers	15	27.8	5.82± .03	5.93± .17	30.14± 5.19	1.76± .29	43.5
All phenotypes	54	100	5.92	5.45	83.11	4.35	107.4
593:							
Normals	49	90.7	5.79± .02	6.73± .03	94.54± 3.72	6.27± .21	154.8
Offtypes	0	0					
Aberrants	2	3.7	6.36± .55	7.41± .37	15.50± 2.20	1.16± .14	28.6
Slow growers	3	5.6	5.93± .02	7.61± .16	17.03± 5.07	1.29± .37	31.9
All phenotypes	54	100	5.82	6.80	87.31	5.81	143.5
All strains:							
Normals	272	72.0	5.84± .01	6.09± .02	105.80± 1.84	6.35± .10	156.8
Offtypes	47	12.4	5.84± .03	5.58± .15	86.58± 4.87	4.72± .27	116.6
Aberrants	10	2.6	5.63± .28	6.14± .32	24.30± 3.79	1.42± .17	35.1
Slow growers	49	13.0	5.87± .03	6.38± .13	26.23± 2.53	1.66± .16	41.0
All phenotypes	378	100	5.84	6.07	90.94	5.41	133.6

leaf characteristics, and growth. The offtypes differed from the normals in flower and leaf characters. Offtypes may arise from mechanical mixing of seed or as segregates from heterozygous parents. The slow growers started growing late in the growing season or grew very slowly after transplanting. They resembled the normals in leaf shape but were considerably smaller. The aberrants were of about the same size as the slow growers, but their leaves were thick and irregular, their flower stalks were usually thicker than those of the normals, and their flowers were usually larger and often distorted; these plants were described by Stebbins and Kodani (*8*) as autotriploid and by Powers and Rollins (*5*) as aberrant.

Significant and highly significant t values (*3*, *7*) were obtained when the mean differences in rubber content, shrub weight, and rubber yield for the four phenotypes were tested. This was true both within and among strains. The percentage of plants in the four classes did not agree with expectation of homogeneity but yielded a highly significant χ^2 (table 3). The resin content was uniform for strains and for phenotypes. The normal plants were superior in all cases for shrub weight and rubber yield. Thus, in order to improve rubber yields, it would be desirable to eliminate the offtypes, aberrants, and slow growers from the commercial strains.

TABLE 3.—χ^2 *for phenotypic frequencies for 7 commercial strains of guayule*

Commercial strain	χ^2 for indicated class				Total χ^2
	Normals	Offtypes	Aberrants	Slow growers	
109	3.64	10.28	0.26	1.29	15.47
130	2.13	4.85	.11	1.29	8.38
405	2.04	4.19	.26	1.29	7.78
406	3.17	4.85	.11	3.57	11.70
407	.02	2.76	1.40	.57	4.75
416	2.04	.01	.26	9.14	11.45
593	2.62	6.70	.26	2.29	11.87
Total χ^2	15.66	33.64	2.66	19.44	71.40**

**>0.01 level of probability.

A comparison of the normal plants of all strains showed the superiority of 109 in rubber yield. This strain ranked first in rubber content and second in shrub weight. Normals of 405 produced the highest shrub weight. A combination of the high rubber content of 109 and the shrub weight of 405 would produce about 218 pounds of rubber per acre; this is a 13-percent increase over the normals of 109. The normals of 416 produced the lowest rubber yield; although they ranked fourth in shrub weight, the low rubber content lowered the rubber yield.

Stebbins and Kodani (*8*) reported that James Bonner found the rubber content highest in the twigs of 6-month- to 1-year-old plants of 74-chromosome guayule (72±-chromosome group), lowest in the 36-chromosome plants, and intermediate in the 54- to 58-chromosome and the 108- to 111-chromosome plants. From this it was inferred that these were preliminary data regarding the relation of rubber content and chromosome number. As no measure of the amount of variability present in Bonner's material was given, it is not known whether the differences were genetic or were manifestations of sampling variability. Also, the strains used may not have been representative samples of the chromosome groups. In addition, it may be pointed out that only a fair relation ($r=0.668$; see table 4) was found between rubber contents of the branch sample and the rest of the plant.

The data from this test indicate that the normal 1-year-old plants of the 54±-chromosome guayule strain (109) are significantly higher in rubber content than those of the strains from the 72±-chromosome group (130, 405, 406, 407, 416, and 593). On the average the aberrants were slightly but not significantly higher than the normal plants in rubber content. For this experiment no statement can be made regarding rubber content and chromosome number for guayule because there were not enough strains to be representative of either chromosome group. The frequency distribution for rubber content of the branch (see table 5) indicates that it would be risky to draw conclusions from a few samples. Apparent differences under conditions of inadequate sampling may be due to the variability in the strains.

Relation Between Plant Characters

NATURE OF THE RELATION

Scatter diagrams were prepared for each of the comparisons of the plant characters studied without regard to strain differences. Upon inspection of the diagrams it was evident that the relations between height, spread, and shrub weight were curvilinear. A transformation of the data to logarithms was made for these characters. The scatter diagrams of the transformed data showed the relations to be linear. The relations of the remainder of the comparisons were linear; hence, no transformation of the data was made. When the data were treated as described, linear regression explained the deviations due to regression and the calculations were simplified.

The increase in spread for a large plant was greater per unit increase of height than for a small one. This fact accounts for the curvilinearity of the regression for these characters. In a like manner the increase in shrub weight per unit increase of height or spread was greater for a large plant than for a small one. Hence, it follows that the relation between shrub weight and height or spread probably is a function of the total surface area or the volume of the aerial portion of the plant rather than of the spread or the height alone.

The amount of the variance in plant spread unexplained by the linear regression of spread on height was 26 percent for the untransformed data and 19 percent for the transformed. Thus, 81 percent of the variance in spread was associated with correlated changes in height when the logarithmic transformation was used. The logarithm of the shrub weight was correlated with the logarithm of height to the extent of 0.911, whereas a lower correlation, 0.827, was obtained from the untransformed data. For transformed data 83 percent of the variance in dry weight of shrub was associated with the correlated changes in plant height. Ninety-one percent of the variance in the logarithm of shrub weight was associated with the correlated changes in the logarithm of plant spread (transformed data), whereas only 82 percent was associated where the data were not transformed. For these three comparisons the logarithmic transformation decreased the amount of the variance unexplained by linear regression from one-fourth to one-half of that obtained by not employing the transformation.

CORRELATION AND REGRESSION COEFFICIENTS

From the data in table 4 it is evident that spread and height were reliable characters for predicting shrub weight. Also, the circumference of the crown, a character used by many workers to give an indication of growth in fruit trees, was a good indicator of shrub weight; but the difficulty in taking this character without digging the plant would make it impractical. A multiple correlation coefficient of 0.912 was found for shrub weight on height and spread, while that for the logarithms of shrub weight and height and spread was 0.961. After the transformation of the data to logarithms 92 percent of the variance was explained by regression. This was little better than the correlation between the logarithms of shrub weight and spread. Height did not add much to the information about shrub weight, but as an indication of yield of shrub it may be well to record both height and spread.

Rubber content of the branch was the only one of the recorded characters sufficiently related to rubber content of the plant to warrant consideration for selection purposes. Size or diameter is a helpful indicator for the betterment of sampling techniques for branch samples. To remove some of the variability for the rubber content of the branch, samples should be of the same or nearly the same diameter. Unpublished data of Holmes [7] indicated that the rubber content of the branch samples from different parts of the plants varied significantly. To obtain a relative comparison among individual plants and strains, it may be well to control these sources of variation by the proper experimental designs. Also, it was possible to remove some of the sampling variation by correlating means of branch samples with means of the same plants. Furthermore, if the rubber content was determined for composites of the branch samples and of the plants from which the branch samples came, the amount of the variation explained by the regression of rubber content of the branch on that of the plant would be as large as that obtained or larger. It would be larger whenever there is sampling variation in rubber-content determinations.

The individual *r* values for strains for rubber content of branch on diameter of wood give an indication of one of the sources of variation in the rubber content of the branch. It is noteworthy that the correlation coefficient nearest zero was for strain 405 and that the one for rubber contents of the branch and of the plant was the highest for this entry. The latter was lowest for strain 130 for which the correlation for rubber content of the branch on diameter of the wood was the highest. In view of this it is likely that varying the size of branch affects the variation in rubber content of the branch and thus the correlation between rubber contents of the branch and of the plant.

The correlation coefficient for shrub weight on green weight of plant was high; by removing the differences between replicates it

[7] HOLMES, R. L. Unpublished data of Special Guayule Research Project.

TABLE 4.—*Correlation (r) and regression (b) coefficients for various characters of 1-year-old plants of 7 commercial strains of guayule*

Linear relation	Comparisons for— Each strain	Comparisons for— Total	Coefficient	Value for strain 109	130	405	406	407	416	593	Value for total
	Number	*Number*									
Log of spread on log of height	50	350	r	0.913**	0.819**	0.904**	0.882**	0.906**	0.937**	0.878**	0.898**
			b	1.06	.996	.915	1.16	.970	1.03	.881	.987
Log of shrub weight on log of height	50	350	r	.928**	.870**	.891**	.843**	.939**	.949**	.927**	.911**
			b	2.60	2.50	2.39	2.32	2.28	2.83	2.30	2.46
Log of shrub weight on log of spread	50	350	r	.964**	.946**	.944**	.960**	.953**	.974**	.940**	.952**
			b	2.32	2.23	2.50	2.00	2.17	2.64	2.32	2.34
Shrub weight on circumference of crown	50	350	r	.838**	.618**	.857**	.634**	.740**	.774**	.691**	.758**
			b	27.7	21.8	32.2	24.3	26.5	29.4	25.2	27.2
Shrub weight on green weight of plant	50	350	r	.964**	.918**	.971**	.912**	.915**	.967**	.948**	.948**
			b	.317	.315	.342	.337	.354	.348	.320	.334
Rubber content on shrub weight	50	350	r	−.239	−.207	−.398**	−.263	−.084	−.499**	−.630**	−.302**
			b	−.005	−.003	−.007	−.006	−.001	−.009	−.012	−.007
Dry weight of leaves on shrub weight	10	70	r								.900**
			b								.314
Resin content on rubber content of plant	50	350	r	.480**	.063	.362**	.227	.419**	.527**	.230	.239**
			b	.334	.072	.279	.198	.298	.286	.160	.150
Rubber content of branch on rubber content of plant	[1] 54	377	r	.689**	.222	.745**	.595**	.659**	.411**	.413**	.668**
			b	.907	.481	.692	.870	1.10	.464	.755	.950
Mean rubber content of branch on mean rubber content of plant for 6 plants	9	63	r								.806**
			b								1.25
Rubber content of branch on diameter of wood	[2] 22	153	r	.310	.542**	.085	.152	−.236	.185	.384	.163*
			b	.003	.008	.001	.003	−.003	.003	.005	.003
Proportion of wood on rubber content of branch	[2] 22	153	r								−.077
			b								−.005
Proportion of wood in branch on rubber content of plant	[2] 22	153	r								−.162*
			b								−.014

*>0.05 level of probability; **>0.01 level of probability.

[1] Except for 130 for which n=53.

[2] Except for 130 for which n=21.

could be increased. Such differences were due mainly to the fact that different intervals elapsed between the times of digging and weighing of the plants from the different replicates. This was quite evident from the scatter diagram of these two characters. That is, the plants from some replicates dried out more than those from others before the green weights were taken. Time interval had no effect on shrub weight, since the plants were dried to oven dryness some time after they had been air-dried. On the average, one-third of the green weight of the plant was shrub weight and the rest was moisture, dirt, and leaves. Green weights are useful in isolating errors in shrub weights and in strain-yield comparisons.

A highly significant negative correlation was obtained for rubber content of the plant on shrub weight (table 4). It has little value from a practical standpoint, because it was low and the negative relation may have been caused by the fact that the aberrants and slow growers had average higher rubber contents and lower shrub weights than the offtype plants (table 2). Even in the case of strain 593, for which the correlation was highly significant, the regression of rubber content on shrub weight of the plant was small. For every 100-gm. increase in shrub weight the decrease in rubber content was 1.24 percent. A 100-gm. plant with 7 percent of rubber would produce 7 gm. of rubber; a 200-gm. plant would contain 5.76 percent of rubber, but it would produce 11.52 gm. of rubber. In view of this and the fact that *r* was relatively low, there appear to be good possibilities for increasing yield of rubber by selecting larger plants.

The relation between resin and rubber contents of the plant was highly significant, but only a small percentage of the variation in rubber content was explained by regression. The *r* values for 109, 405, 407, and 416 were highly significant statistically; but they were not significant for 130, 406, and 593, which are very much alike phenotypically. Thus, there appeared to be a difference in groups with respect to the relation of these characters. In any event the relation was not high enough to prevent selection for each character almost independently.

Frequency Distributions of Plant Characters

The frequency distributions (table 5) give the experimenter in guayule an indication of the variability in plant characters. For such characters as shrub weight, weight of rubber, and rubber and resin contents of the branch the frequency distributions indicate that gross errors in conclusions may result when experiments are based on too few plants. With such heterogeneous populations the probability of getting plants for different treatments from opposite ends of the distribution is not improbable for small samples. Consequently, because of the confounding of the genotype and treatment effects, no reliable statement could be made regarding the treatment.

The distributions of plant height and spread were skewed to the left, whereas the distribution of shrub weights was fairly well scattered but approached normality. A comparison of the distributions of rubber contents of the plant and of the branch reveals the greater variability in the branch samples. Therefore, the variability for this character should be reduced in order to obtain reliable estimates of

TABLE 5.—*Frequency distributions of 11 plant characters of 1-year-old plants of 7 commercial strains of guayule*

Plant character		Class heading and frequency in each class															Total
Height	Class (cm.)	1–5	6–10	11–15	16–20	21–25	26–30	31–35									
	Frequency	0	7	23	33	110	163	42									378
Spread	Class (cm.)	1–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–45	46–50						
	Frequency	0	2	7	15	28	26	86	112	87	15						378
Green weight of plant	Class (gm.)	1–50	51–100	101–150	151–200	201–250	251–300	301–350	351–400	401–450	451–500	501–550	551–600	601–650			
	Frequency	19	24	20	36	75	64	41	38	16	9	6	1	1			350
Shrub weight	Class (gm.)	1–20	21–40	41–60	61–80	81–100	101–120	121–140	141–160	161–180	181–200						
	Frequency	26	26	30	47	86	78	45	23	14	3						378
Circumference of crown	Class (cm.)	2.6–3.0	3.1–3.5	3.6–4.0	4.1–4.5	4.6–5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6–7.0	7.1–7.5	7.6–8.0	8.1–8.5	8.6–9.0	9.1–10.0	10.1–10.5	
	Frequency	8	7	12	17	22	42	75	84	38	25	11	7	1	0	1	350
Weight of rubber	Class (gm.)	0.1–1.0	1.1–2.0	2.1–3.0	3.1–4.0	4.1–5.0	5.1–6.0	6.1–7.0	7.1–8.0	8.1–9.0	9.1–10.0	10.1–11.0	11.1–12.0	12.1–13.0			
	Frequency	17	28	21	31	47	67	82	37	26	15	6	0	1			378
Rubber content of plant	Class (percent)	1.6–2.0	2.1–2.5	2.6–3.0	3.1–3.5	3.6–4.0	4.1–4.5	4.6–5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6–7.0	7.1–7.5	7.6–8.0	8.1–8.5	8.6–9.0	
	Frequency	1	0	1	0	2	13	20	54	85	92	63	28	14	3	2	378
Rubber content of branch	Class (percent)	2.1–2.5	2.6–3.0	3.1–3.5	3.6–4.0	4.1–4.5	4.6–5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6–7.0	7.1–7.5	7.6–8.0	8.1–8.5	8.6–9.0	9.1–9.5	
	Frequency	5	8	14	38	36	40	62	44	51	41	17	13	6	1	1	377
Resin content of plant	Class (percent)	2.1–2.5	2.6–3.0	3.1–3.5	3.6–4.0	4.1–4.5	4.6–5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6–7.0	7.1–7.5	7.6–8.0	8.1–8.5	8.6–9.0		
	Frequency	1	0	1	2	3	12	55	172	103	23	5	0	0	1		378
Resin content of branch	Class (percent)	4.1–5.0	5.1–5.5	5.6–6.0	6.1–6.5	6.6–7.0	7.1–7.5	7.6–8.0	8.1–8.5	8.6–9.0	9.1–9.5	9.6–10.0	10.1–10.5	10.6–11.0	11.1–11.5	11.6–12.0	
	Frequency	2	6	13	17	33	67	39	51	34	34	24	21	11	9	3	364
Proportion of wood in branch	Class (percent)	0.51–0.55	0.56–0.60	0.61–0.65	0.66–0.70	0.71–0.75	0.76–0.80	0.81–0.85	0.86–0.90	0.91–0.95							
	Frequency	1	6	38	47	27	16	21	9	3							168

rubber content of the plant. The distribution of rubber content of the plant was normal or nearly normal, whereas that of rubber content of branch had fewer individuals in the classes around the mean than a normal distribution should have. This was also true for resin content of the branch. The resin content of the plant was very uniform, and the distribution was normal.

Since these plants were selected at random, they are a good estimate of the amount of variability in 1-year-old plants of the seven commercial strains of guayule as grown from nursery stock. It is the practice of the nursery to cull and discard the smaller plants; it seems quite likely, then, that some of the plant types may have been discarded in culling operations. Hence, some of the genetic variation may have been discarded and, therefore, the variability of these varieties may be greater than the estimates presented.

Emergence and Uniformity-of-Type Data for Open-Pollinated, Individual-Plant Selections

For a more successful crop, guayule strains which are relatively high in percentage of emergence, require a short period for emergence, and are uniform with respect to type and growth characteristics are needed. In an attempt to improve the seven commercial strains of guayule with respect to these three characters, a large number of open-pollinated, individual-plant selections (table 6) were made.

Table 6.—*Range in means for percentage and time of emergence and proportion of aberrants and offtypes in 8 tests on individual-plant selections from commercial strains of guayule*

Commercial strain from which selections were made	Selections in test	Range of character					
		Plants emerging		Time of emergence after planting		Proportion of offtype and aberrant plants	
		High	Low	Earliest	Latest	Low	High
	Number	*Percent*	*Percent*	*Days*	*Days*	*Percent*	*Percent*
109	62	6.0	0	6.0	13.0	0	33
130	49	6.7	.7	6.7	10.4	0	80
405	121	12.0	.3	6.6	12.0	0	43
406	49	9.3	.7	5.7	9.4	0	100
407	343	9.7	.3	6.0	13.0	0	75
416	48	6.7	.3	5.0	11.3	0	100
593	727	19.7	.3	5.7	12.2	0	100
Miscellaneous	80	13.3	0	6.8	21.5	0	100

The percentage of emergence and the frequency of occurrence of aberrant and offtype plants may or may not have been influenced if the parent selection had been isolated (*5*).[8] The phenomena of fertilization and incompatibility may alter the expression of these two characters. Powers and Rollins (*5*) showed that the frequency of occurrence of aberrants and offtypes from selfed material was usually lower than from open-pollinated material. On the basis that reproduction in the chromosome groups containing the seven commercial strains was found to be largely pseudogamous (*5*)[8], the progeny from open-

[8] Powers, L. Unpublished data of Special Guayule Research Project.

pollinated material will resemble the maternal plant to a large degree. Because of this fact and the impracticability of selfing such a large number of selections, open-pollinated material was used. The effect that *Lygus* spp. (*6*), nutrients (*9*), and climate[9] may have had on this low emergence percentage was not known definitely. *Lygus* spp. have been shown to have some effect. Powers[10] and Powers and Rollins (*5*) have shown that the major cause of low percentages of emergence is genetic. Such factors as male sterility and incompatibility complicate the problem of obtaining selections which are high in emergence.

From a practical standpoint the best selections as grown in this test are much lower in emergence than desired. Therefore, the only hope for obtaining strains high in emergence is to obtain a wider base for selection than these seven commercial strains offer. Despite this fact, however, the seven commercial strains can be improved by selection.

By use of the χ^2 test the differences among the selections for percentage of emergence were found to be statistically significant. Therefore, individual plants can be selected from these heterogeneous strains for a higher percentage of emergence. Selections from 593 appeared to offer the best possibilities for higher emergence percentages.

Significant differences were found to exist among the selections within an experiment for earliness of emergence. Selection for this character appears equally good in all the strains. The selections within a strain were found to differ significantly with respect to the frequency of aberrant and offtype plants. A large proportion of the progeny of the selections of 109 were free from aberrant and offtype plants. This was an indication that a large percentage of the nonnormal plants of 109 come from a mechanical mixture. This strain offers considerable promise in selecting plants whose progeny produce few or no aberrant and offtype plants.

In the miscellaneous experiment aberrants and offtypes were included to determine their breeding behavior. In all cases the offtype plants produced progeny similar to the parent plant; that is, an offtype plant from strain 109 produced offtype plants rather than normal plants of 109. The aberrant plants produced mostly aberrants. However, some normal plants occurred in the progeny of the aberrant plants. The explanation for this phenomenon is not known.

In addition to the variability previously shown (tables 1 to 5) for the seven commercial guayule varieties, these data (tables 6 and 7) make it evident that considerable work is required before a uniform variety of guayule can be produced. A strain that is heterogeneous and heterozygous for the time and percentage of emergence and for the type of plant is very likely not homogeneous and homozygous for other characters. In support of this contention some selections were uniform for growth in each of the three replicates whereas others were extremely variable. No measurements for uniformity of growth were recorded, and the heterogeneity for this character is from observation only.

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[9] BENEDICT, H. M. Unpublished data of Special Guayule Research Project.

[10] See footnote 8, p. 12.

TABLE 7.—*Time-of-emergence results for individual-plant selections from commercial strains of guayule*

Commercial strain from which selections were made [1]	Proportion of plants emerged by specified time after planting									Total plants emerged
	4 days	6 days	8 days	10 days	12 days	14 days	16 days	18 days	25 days	
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
109	1.1	21.5	57.2	82.7	92.9	97.3	99.2	100	100	529
130	1.4	31.8	67.2	89.2	93.1	98.4	99.0	100	100	491
405	2.0	33.7	67.0	88.8	95.7	98.6	99.5	99.9	100	2,060
406	7.6	47.1	76.2	91.5	95.5	97.6	98.9	100	100	621
416	8.3	47.8	73.7	90.1	96.1	98.2	98.9	99.8	100	433
593	1.8	19.9	59.4	82.7	93.0	96.5	98.1	98.8	100	11,220
Miscellaneous	.2	15.9	59.9	82.5	95.0	97.2	98.2	99.3	100	1,157
All strains	2.1	23.5	61.6	84.2	93.7	97.0	98.4	99.1	100	16,511

[1] Test on selections of 407 not included, as the counts were made on a different sequence of days.

In the formation of an improved strain selfed progeny from the better selections in these tests should be isolated and tested for the desired characteristics. Then the better selections from this test would be bulked, and an improved variety would result. The first step in the improvement of existing strains is the elimination of undesirable types; these are selections which are low or slow in emergence, which contain a high percentage of aberrants and offtypes, or which are not uniform for growth.

The proportion of the plants emerging on a specified day after planting is presented in table 7. Slight differences existed among the commercial strains in the percentages emerging on the different days, but in all cases about 97 percent of the plants had emerged within 2 weeks after planting.

DATA FROM STRAIN TEST

PERCENTAGE OF ABERRANTS

As the aberrant plants were smaller than the nonaberrants (normals, offtypes, and slow growers), the yield of shrub would be affected inversely by the percentage of aberrants in a strain. Hence, the superior strains would be those which produce few or no aberrants. The magnitude of the size difference is estimated in table 2 for the seven commercial strains and in table 11 (p. 19) for the entries in the strain test.

The percentage of aberrants was recorded for each of the 44 entries in the strain test. Although none of the strains were free from aberrants, some were nearly so. Strain 42478 produced 2 and 3 percent of this plant type, and strains 42475 and 42435 each produced 4 percent. These 3 selections were superior to all the other strains in this test. At the other end of the range 42451 and 42469 produced 58 percent of aberrant plants. Thus, there was considerable variation among the strains. The amount of variation within each of these strains was not known, but in light of evidence presented earlier in this paper (table 6) it appeared possible to select from some strains individual plants which do not produce aberrant plants. The 8 strains designated as commercial (table 8) were quite different with respect to the number of aberrants produced. Among these strains, 42475 produced the lowest percentage of aberrants and 42474 and 42440 the highest. Thus 1 in 25 plants of 42475 was aberrant, while more than 1 in 4 of 42474 and 42440 was aberrant. Such a high frequency of aberrant plants as occurred in the last 2 seriously affects the yield of shrub per acre, which necessarily affects the yield of rubber per acre.

TABLE 8.—*Percentage of aberrant plants of 42 strains of guayule in the strain test*

Strain	W. B. McCallum's designation	Aberrants in 240 plants	Strain	W. B. McCallum's designation	Aberrants in 240 plants
		Percent			*Percent*
42478	Mexican plant	2±0.9	42480	404	20±2.6
42478	do	[1] 3±1.6	42465	439	20±2.6
42475 [2]	109 (commercial)	4±1.3	42436	405 (commercial)	20±2.6
42435 [2]	109	4±1.3	42467	441	22±2.7
42445 [2]	111	8±1.8	42449 [2]	255	25±2.8
42448 [2]	210	8±1.8	42474	406 (commercial)	27±2.9
42460	418	8±1.8	42440	130 (commercial)	28±2.9
42473 [2]	111 (commercial)	8±1.8	42447	130	30±3.0
42458	411	9±1.9	42450 [2]	258	32±3.0
42477	416 (commercial)	[3] 10±3.1	42438	444	34±3.1
42468	453	10±1.9	42446	130–32M	40±3.2
42468	453	11±2.0	42471	459–A	[4] 41±4.1
42452	404	12±2.1	42470	459	42±3.2
42456	405–2	12±2.1	42457	406–F	43±3.2
42476	407 (commercial)	[1] 15±3.3	42471	459–A	44±3.2
42454	405	15±2.3	42437	406–B	47±3.2
42453	404–A	15±2.3	42472	735–2	49±3.2
42455	405–1	16±2.4	42466	440	50±3.2
42462	426	16±2.4	42463	428	54±3.2
42459	413	17±2.4	42464	430	55±3.2
42441	593 (commercial)	18±2.5	42444	49	55±3.2
42461	419	18±2.5	42451	402	58±3.2
42441	593 (commercial)	19±2.5	42469	456	58±3.2

[1] 120 plants.
[2] 54±-chromosome group; the remainder in the 72±-chromosome group.
[3] 96 plants.
[4] 144 plants.

The range in frequency of aberrants for the 54±-chromosome group was from 4 to 32 percent. This range was not as great as that for the 72±-chromosome group. This does not mean that the range in the population for the strains with fewer chromosomes is smaller but probably reflects the difference in the number in each group, 7 strains in the 54±-chromosome group and 35 in the 72±-chromosome group.

As stated under Materials and Methods, the plants in the strain test represent the progeny from the 7 strains in the commercial-strain test and from 35 others. There is no disagreement between the percentages of aberrants in this experiment and in the commercial-strain test. The difference was due to the fact that the material in the latter was culled at the nursery before transplanting. This lowered the frequency of occurrence of the aberrant plants. The same factor explains the differences between comparable strains in this test and the material reported by Stebbins and Kodani (*8*, *table 1*). It was known that some of the strains were culled before Stebbins received them. Hence, these deviations represent the intensity of culling operations. Other phenomena, such as time of seed set and fertilization as affected by environmental changes, insect populations, or foreign pollen, may result in a change in the frequency of expression of this phenotype. Discarding certain type plants was known to be one of the causes of, if not the cause of, the differences reported in these three instances for frequency of aberrants.

A homogeneity test on the 42 entries which appeared in all 20 replicates for the frequency of aberrants in each plot of 12 plants gave a value of 27.24 for $\sqrt{2\chi^2}-\sqrt{2n-1}$. Since 27.24 was materially greater than 2, it was assumed that the value of χ^2, 662.94, was not in accordance with the expectation that the strain variances were homogeneous. Also the frequency distribution was skewed to the right. There were 122 plots which had no aberrants; 152 with 1; 136 with 2; 102 with 3; 95 with 4; 73 with 5; 66 with 6; 48 with 7; 31 with 8; 10 with 9; 5 with 10; and 0 with 11 or 12. In light of this evidence χ^2 instead of the analysis of variance was employed to find the probability of differences between strains with respect to the frequency of aberrant plants.

The χ^2 value for strains equals 1,502.75 (table 9). The probability that this large value was due to chance is extremely small. Hence, it was assumed that there were real differences between strains with regard to the frequency of aberrants. The low value of χ^2 for replicates fulfills expectation. There should be no difference between replicates with regard to the frequency of aberrants. The interaction χ^2, strains $\times$ replicates, represents sampling variation of the number of aberrants in each plot. It has no biological significance. The interaction χ^2 is 792.66. The value for $\sqrt{2\chi^2}-\sqrt{2n-1}$ is 0.35, which agrees with expectation. That is, the differences in distribution of aberrants for the different strains over the different replicates did not vary any more than may be attributed to chance.

A check on the accuracy of classifying aberrants was afforded in 4 instances. The 2 entries of strain 42441 agreed very well; in one 18 percent of the plants were aberrant and in the other 19 percent. The 2 entries of 42468 produced 10 and 11 percent of aberrant plants. The entry of 42478 used in all 20 replicates produced 2 percent of aberrants and that used in only the last 10 replicates produced 3 percent. The entry of 42471 used in all 20 replicates produced 44 percent of aberrants and that used in only the last 12 replicates produced 41 percent of aberrant plants. This close agreement of the 2 separate and independent samples for these 4 strains reflected the accuracy of classification and distribution of the aberrant plants in the different strains. This confirmed the high χ^2 value for strains and the low one for replicates.

TABLE 9.—*χ^2 values for the different components for occurrence of aberrants in strains of guayule*

Source of variation	Degrees of freedom	χ^2	$\sqrt{2\chi^2}-\sqrt{2n-1}$
Strains	41	1,502.75	45.82
Replicates	19	17.67	
Strains $\times$ replicates	779	792.66	.35
Total	839	2,165.36	

HEIGHT AND SPREAD OF ALL PLANTS

Growth measurements (height and spread) for the strains in the strain test were recorded (table 10) on 2 different dates, the first during the latter part of May in the greenhouse and the second during the middle of August in the field. The agreement between the plant heights in May and in August was not very close, the correlation being 0.534 for all the plants in the first 10 replicates. Thus, about 28 percent of the variance of the plant heights in August can be accounted for by that in May. In other words, the agreement between the plant heights in the greenhouse and field was too low to be of use in predicting plant heights in the field.

The correlation between the logarithms of the plant height and spread in August for all plants in the first 10 replicates was 0.903. Therefore, about 82 percent of the variance in height was accounted for by the variation spread. The correlations for the individual strains ranged from 0.808 to 0.971. Since both spread and height are important in determining the total weight of a plant, they are useful in determining which strains are superior in yield of shrub.

TABLE 10.—*Means and standard errors for plant height and spread of 42 strains of guayule in 20 replicates at 2 stages of growth in the strain test*

Strain [1]	Plant height				Plant spread			
	May 1943	Rank	August 1943	Rank	May 1943	Rank	August 1943	Rank
	Cm.		*Cm.*		*Cm.*		*Cm.*	
42478 [2]	7.26±0.68	2	19.00±0.54	1	5.44±0.62	28	20.90±1.33	1
42478	6.74± .36	6	18.15± .48	2	5.60± .35	22	20.15± .85	2
42471 [3]	7.63± .55	1	16.58± .70	3	8.63± .75	1	20.08±1.07	3
42435	7.02± .31	3	16.55± .44	4	6.26± .43	9	18.60± .79	19
42460	6.57± .30	7	16.45± .59	5	6.68± .48	4	19.60± .97	4
42449	6.54± .38	9	16.45± .59	6	5.98± .40	17	16.80± .80	36
42458	6.08± .33	23	16.35± .55	7	5.82± .40	21	18.90± .95	12
42450	5.72± .36	36	15.90± .57	8	5.05± .41	33	16.05± .74	46
42467	5.66± .37	38	15.75± .42	9	5.18± .47	31	19.15± .77	7
42462	6.16± .27	20	15.65± .45	10	6.53± .38	5	19.10± .88	8
42441	5.74± .28	34	15.50± .50	11	4.68± .27	43	16.45± .80	41
42465	5.66± .31	39	15.45± .54	12	5.25± .47	29	18.75± .92	17
42470	6.54± .38	8	15.45± .48	13	6.70± .50	3	18.75± .78	18
42472	6.38± .27	11	15.45± .43	14	6.20± .32	10	18.80± .83	15
42453	6.06± .31	24	15.40± .48	15	6.12± .40	13	19.05± .79	9
42475	6.26± .30	15	15.35± .44	16	6.04± .41	16	18.05± .67	25
42473	5.77± .39	33	15.30± .49	17	4.87± .39	36	17.55± .84	31
42463	6.74± .36	4	15.30± .43	18	6.96± .52	2	18.55± .66	20
42480	6.21± .35	16	15.25± .51	19	5.98± .58	18	18.85± .74	14
42448	5.94± .31	26	15.25± .45	20	5.04± .30	34	17.40± .71	32
42452	6.20± .26	17	15.20± .52	21	6.26± .47	8	18.95± .80	11
42446	5.98± .28	25	15.15± .39	22	5.22± .26	30	16.75± .56	37
42441	5.90± .31	30	15.10± .51	23	4.84± .31	40	16.45± .81	42
42474	5.83± .29	32	15.10± .46	24	4.84± .24	39	16.65± .74	40
42461	5.90± .36	29	15.05± .59	25	5.48± .52	26	18.90± .93	13
42456	5.86± .32	31	15.05± .52	26	5.48± .45	27	19.20± .81	5
42445	6.13± .29	22	15.05± .48	27	5.17± .31	32	17.65± .80	29
42469	6.74± .30	5	15.05± .43	28	6.16± .43	11	18.10± .72	24
42454	6.34± .33	12	15.05± .40	29	6.46± .45	6	19.00± .76	10
42444	5.58± .30	42	14.95± .46	30	4.86± .32	37	16.70± .77	39
42466	6.32± .28	13	14.90± .48	31	6.11± .39	14	18.20± .87	21
42447	5.63± .31	40	14.90± .42	32	4.65± .38	44	16.75± .75	38
42464	6.15± .31	21	14.90± .33	33	5.88± .44	19	18.00± .70	26
42451	6.38± .37	10	14.85± .45	34	6.04± .43	15	18.10± .76	23
42459	6.17± .30	19	14.85± .45	35	6.28± .49	7	18.15± .74	22
42471	6.28± .41	14	14.75± .44	36	5.84± .52	20	17.60± .82	30
42457	5.92± .29	27	14.65± .48	37	4.85± .28	38	16.15± .72	43
42477 [4]	6.20± .22	18	14.62± .60	38	6.12± .30	12	18.00±1.05	27
42468	5.37± .32	45	14.60± .51	39	4.70± .33	41	17.35± .82	33
42436	5.74± .35	35	14.60± .46	40	5.55± .51	25	18.75± .76	16
42440	5.92± .22	28	14.50± .43	41	4.68± .21	42	16.05± .70	45
42455	5.62± .38	41	14.40± .54	42	5.58± .59	23	19.15± .90	6
42437	5.42± .31	44	14.35± .41	43	4.94± .45	35	16.95± .66	35
42438	5.67± .24	37	14.25± .46	44	4.56± .27	45	16.05± .63	44
42476 [2]	5.44± .32	43	14.10± .55	45	5.58± .53	24	17.80±1.03	28
42468	4.41± .29	46	13.95± .48	46	3.82± .27	46	17.05± .74	34

[1] See table 8 for W. B. McCallum's designations.
[2] 10 replicates.
[3] 12 replicates.
[4] 8 replicates.

It is not known at present whether there is an interaction between the yield of shrub and age for these guayule strains. There was an interaction between the greenhouse and field measurements for first-year material. This may have been caused partly by differences in time of seed germination, which spread out over a 2-week or longer period. These early differences may have been removed by the time the second measurement was recorded. Future data may clarify this point.

From the standpoint of both height and spread, 42478, 42460, 42435, 42458, 42467, and 42462 were among the superior strains in the test. The inferior strains in the experiment were 42438, 42440, 42437, and 42468. In the 54±-chromosome group 42435 was the tallest and widest, whereas 42450 was the narrowest and 42445 the shortest. The strains from both chromosome groups apparently grew equally well in this experiment. The strains listed as commercial were inferior in growth to the best strains in the test.

Means and Variances of Height for Aberrants and Nonaberrants

Heights for aberrant and nonaberrant plants (normals, offtypes, and slow growers) in the first 10 replicates were computed (table 11). In every case the nonaberrant plants of a strain were taller than the aberrants. As an increased percentage of aberrant plants in a strain affects the yield, it would be desirable to select strains in which few or no aberrant plants occur. The rankings of the strains are different from those in table 10, in which aberrants and nonaberrants are not separated. If it is possible to select individual plants which do not produce aberrants, table 11 gives an estimate of the probable rankings of these strains for plant height. Strain 42478 remained in first position, but the removal of aberrant plants changed the ranking of strain 42444 from thirtieth to second place. The rankings of some strains were changed materially while others, such as 42468 and 42455, remained in about the same position; these are among the shortest strains in the test. Strain 42435 produced the tallest aberrants and strains 42478 and 42450 the next tallest. Strains 42468 and 42441 produced the shortest aberrant plants on the average. The range between the means of the aberrant plants was greater than that between the means of the nonaberrants. The strains averaging the tallest nonaberrant plants did not necessarily average the tallest aberrants. Strain 42450 ranked twenty-fourth in plant height of the nonaberrant plants and third in plant height of the aberrants. Strain 42441 ranked twenty-first and twenty-second in plant height for nonaberrant plants and forty-first and forty-second for the aberrants.

In addition to the strain means for aberrant and nonaberrant plants the variances for the total, the nonaberrant, and the aberrant plants in the first 10 replicates were computed (table 11). In most cases the removal of the aberrant plants decreased the variance; in only 3 out of the 44 cases was the variance of the nonaberrants higher than that of the totals, which included the aberrants. In 2 of these the aberrants were uniform and the means of the 2 classes were not widely different. In the third exception, 42451, the nonaberrant plants were exceedingly variable for plant height, while the aberrants were relatively uniform.

TABLE 11.—*Means, standard errors, and variances for plant height of aberrants and nonaberrants of 42 strains of guayule in 10 replicates in the strain test*

Strain [1]	Total variance	Nonaberrants		Aberrants	
		Mean height	Variance of height	Mean height	Variance of height
		Cm.		*Cm.*	
42478	8.85	18.12±0.27	8.54	13.67±0.88	2.34
42444	19.95	17.87± .42	8.98	11.08± .36	8.08
42463	11.30	16.60± .38	8.31	12.24± .28	4.94
42464	8.20	16.56± .35	5.62	12.89± .25	4.73
42466	12.75	16.55± .41	9.69	12.30± .34	6.89
42469	10.82	16.40± .45	9.96	13.02± .32	6.58
42472	10.09	16.40± .34	7.09	13.38± .39	8.66
42449	14.02	16.26± .37	11.02	13.22± .64	14.69
42446	11.56	16.24± .35	8.53	11.65± .27	3.43
42457	13.47	16.16± .37	9.48	11.44± .35	6.09
42451	9.65	15.91± .47	10.13	13.18± .30	6.56
42460	16.70	15.90± .37	14.70	11.54± .36	17.27
42467	7.96	15.82± .29	7.46	13.00± .38	3.67
42470	10.81	15.82± .32	7.24	11.90± .38	6.99
42435	6.80	15.80± .25	6.99	14.20± .20	.20
42458	8.62	15.66± .27	8.06	13.20±1.01	10.18
42447	12.16	15.65± .33	9.21	11.12± .38	4.83
42462	8.70	15.48± .28	7.54	12.28± .61	6.68
42471	10.74	15.48± .31	6.65	11.28± .37	6.33
42437	10.34	15.43± .40	9.09	11.76± .29	5.04
42441	10.64	15.43± .22	5.00	9.76± .72	10.89
42441	11.67	15.33± .29	8.18	10.09± .46	4.75
42474	12.72	15.33± .35	10.91	11.20± .42	5.41
42450	10.80	15.24± .33	9.20	13.55± .63	13.19
42438	12.77	15.23± .35	9.78	10.83± .42	6.21
42440	11.74	15.21± .32	8.91	11.03± .42	6.32
42453	8.14	15.07± .27	7.13	11.55± .38	2.89
42477 [2]	9.55	15.01± .34	9.29	12.10± .67	4.54
42448	9.28	15.00± .27	8.29	11.88±1.39	15.55
42454	7.99	14.99± .25	6.17	11.19± .68	7.36
42475	7.26	14.99± .25	6.96	12.75±1.89	14.25
42465	9.49	14.96± .31	9.80	12.89± .49	4.54
42480	8.38	14.94± .29	7.54	12.52± .50	6.87
42456	9.11	14.81± .29	8.33	12.18± .70	8.28
42436	9.48	14.77± .31	8.79	12.21± .55	7.22
42461	10.12	14.76± .31	8.77	11.52± .57	7.53
42452	11.41	14.65± .32	10.62	11.33± .71	7.67
42459	8.69	14.60± .30	8.33	11.96± .43	4.71
42476	10.76	14.53± .34	10.74	11.67± .49	4.24
42473	9.99	14.36± .29	9.05	12.22±1.47	19.44
42445	7.43	14.26± .26	6.90	11.40± .78	6.04
42468	9.11	14.16± .23	5.66	7.92± .61	4.45
42468	11.14	13.88± .26	7.24	6.38±1.16	10.84
42455	8.42	13.64± .29	8.07	11.32± .56	6.01

[1] See table 8 for W. B. McCallum's designations.
[2] 8 replicates.

The variances of the nonaberrants for the different strains differed significantly in spite of the fact that the class aberrant plants had been removed.

TIME OF FLOWERING

First bloom on an individual-plant basis was recorded once a week beginning April 3, 1944, and is presented as number of days after April 1. It was required that one or more flowers be fully opened. The plot means, their coefficient of variation, and the standard error of a difference between 2 strain means were calculated from the plot means from the first 10 replicates. The plot mean was computed from the individual-plant dates of first bloom (table 12). The variation within the plot was large for some strains, but the plot was large enough to give a good estimate of the strain mean. This was illustrated by the relatively low coefficient of variation, 10 percent. Since

TABLE 12.—*Mean number of days to first bloom after April 1, 1944, for 42 strains of guayule in 10 replicates in the strain test*

Strain [1]	Mean period [2]	Strain [1]	Mean period [2]	Strain [1]	Mean period [2]
	Days		*Days*		*Days*
42467	21.4	42473	24.0	42470	26.6
42462	22.2	42447	24.4	42475	26.9
42449	22.3	42438	24.6	42446	27.0
42450	22.6	42459	24.6	42466	27.3
42456	22.6	42460	24.6	42451	27.5
42461	22.7	42478	24.7	42464	27.7
42465	22.9	42480	24.7	42463	27.8
42448	22.9	42474	24.8	42472	27.8
42454	23.0	42477 [3]	25.1	42468	28.1
42441	23.1	42458	25.3	42469	28.1
42453	23.1	42445	25.6	42468	29.9
42455	23.1	42457	25.7	42444	37.9
42452	23.2	42435	25.9		
42436	23.2	42471	25.9	Mean	25.2
42476	23.3	42437	26.1		
42441	23.4	42440	26.5		

[1] See table 8 for W. B. McCallum's designations.
[2] Standard error of a difference between 2 plot means equals 1.14 days; coefficient of variation of plot means equals 10 percent.
[3] Mean of 8 replicates.

the strains differed widely with respect to growth characteristics, the variance within a plot was not calculated for first bloom. Individual-plant selections should be made in an attempt to obtain more uniform growth characteristics; then genetic variation of first bloom could be determined. For the present, the relative positions of the means for first bloom offered the information required for strain differences.

Highly significant differences were obtained among both the replicate and the strain means. First-bloom data were affected by location in the field; the replicates from the sandier portion of the experiment bloomed later than did those from the heavier soil types.

The strains varied in average number of days to first bloom from 21.4 for strain 42467 to 37.9 for strain 42444. This range was considerable when the standard error of a difference between 2 plot means, 1.14 days, was so small. There appeared to be no difference in this character between the 54±- and the 72±-chromosome groups. The strains designated as commercials (table 8) were grouped around the experiment average, 25.2 days. None of these were significantly different from the experiment mean, but they were from each other. However, the difference was so small that the selection of one of these strains over another for earliness would be of doubtful value in a breeding program.

Strain 42444 bloomed over 2 weeks later than a number of the other strains. For lateness in blooming strain 42444 appeared to be useful in a breeding program. Strains 42468 and 42469 bloomed about 1 week later than strain 42467. The last-named strain and several others (42462, 42449, 42450, 42456, and 42461) are the most promising as breeding material for earliness of first bloom. Of course there is genetic variability within each strain, but the individual-plant selections from the strains with the earliest strain mean will be the earliest for date of first bloom in the majority of cases.

EMERGENCE AS RELATED TO SEED TREATMENTS

Mass seed selections of the better typical plants from the 42 strains and seed of 7 nonselected collections (42436, 42440, 42441 (in twice), 42474, 42475, and 4263) were tested in a 7 by 7 triple lattice design with 6 replicates. The 4 seed treatments applied to each strain were employed as a split-plot feature of the strain, or whole, plot. The split-plot size was 100 seeds. Hence, the means for number of plants emerged are given in percentage (table 13). The standard errors

TABLE 13.—*Emergence data for 42 selected strains and 7 nonselected collections of guayule given various seed treatments*

Strain [1]	All seed treatments		1943 seed						1942 seed (unthreshed, treated) [2]	
			Threshed, untreated		Unthreshed, untreated		Unthreshed, treated			
	Emergence	Mean period of emergence	Emergence	Mean period of emergence	Emergence	Mean period of emergence	Emergence	Mean period of emergence	Emergence	Mean period of emergence
	Pct.	*Days*	*Pct.*	*Days*	*Pct.*	*Days*	*Pct.*	*Days*	*Pct.*	*Days*
42444 (selected)	30.96	6.84	71.67	6.08	12.33	8.39	11.67	8.97	28.17	7.21
42468 (selected)	30.17	6.83	61.83	5.92	10.33	7.35	20.50	8.57	28.00	7.39
42478 (selected)	29.08	6.14	53.00	5.14	19.50	6.60	10.00	7.42	33.83	7.10
42441 (selected)	25.71	8.50	59.67	7.09	17.00	9.21	13.00	10.50	13.17	11.57
42446 (selected)	25.25	7.43	58.17	6.43	16.17	7.86	8.50	10.02	18.17	9.00
42461 (selected)	24.88	6.95	64.00	6.08	11.83	8.92	7.00	9.33	16.67	7.96
42471 (selected)	24.12	7.93	53.50	6.30	13.83	8.19	10.67	9.67	18.50	11.42
42457 (selected)	23.83	7.46	53.33	6.38	17.00	7.64	11.83	9.46	13.17	9.73
42438 (selected)	23.25	7.27	61.67	6.24	11.33	7.65	9.83	9.68	10.17	11.02
42474 (selected)	22.17	7.33	52.83	6.12	15.33	7.95	8.83	8.58	11.67	11.11
42440 (selected)	22.08	7.12	63.00	6.15	12.33	9.32	5.00	10.13	8.00	10.29
42472 (selected)	21.96	9.27	44.50	8.70	9.50	10.65	4.67	11.93	29.17	9.19
42456 (selected)	21.42	7.09	62.67	6.18	10.67	8.83	3.00	9.67	9.33	10.39
42467 (selected)	21.38	7.03	45.83	5.64	12.00	8.39	5.17	10.00	22.50	8.36
42463 (selected)	20.88	9.38	39.83	8.46	7.50	9.04	10.83	10.69	25.33	10.20
42470 (selected)	20.62	8.83	43.17	7.84	10.00	9.78	6.17	11.32	23.17	9.61
42454 (selected)	20.50	6.65	59.00	5.98	8.00	7.56	4.00	8.50	11.00	8.91
4263 (nonselected)	20.29	8.29	48.83	7.87	7.67	11.07	11.17	8.64	[3] 13.50	8.36
42453 (selected)	20.08	6.76	59.00	6.18	4.50	8.15	4.33	10.08	12.50	7.88
42473 (selected)	20.04	8.34	55.83	7.78	10.00	10.25	3.00	9.78	11.33	9.07
42459 (selected)	19.96	6.78	55.67	6.00	10.67	7.98	4.33	9.42	9.17	9.04
42437 (selected)	19.92	7.79	53.50	6.90	11.67	8.71	9.33	9.98	5.17	10.77
42447 (selected)	19.92	7.57	48.67	6.66	10.50	8.75	9.17	9.07	11.33	8.99
42462 (selected)	19.75	6.63	57.33	5.86	7.33	7.02	4.33	9.31	10.00	9.55
42466 (selected)	19.42	9.40	43.67	8.40	6.00	12.61	5.00	10.27	23.00	10.05
42451 (selected)	19.42	9.12	42.17	8.16	7.67	10.11	8.67	11.29	19.17	9.62
42441 (nonselected)	19.25	7.56	48.83	6.84	9.00	7.94	6.67	8.82	12.50	9.37
42455 (selected)	18.92	7.45	55.83	6.52	7.50	9.44	2.33	11.21	10.00	10.30
42464 (selected)	18.54	9.61	43.83	8.73	9.83	9.54	6.67	9.68	13.83	12.46
42436 (selected)	18.21	6.77	48.50	6.10	11.33	7.00	6.67	8.48	6.33	9.53
42477 (selected)	17.50	6.36	52.17	5.87	11.50	7.13	3.67	8.55	2.67	9.31
42480 (selected)	17.42	7.30	46.00	6.36	9.50	8.63	5.83	8.83	8.33	9.22
42476 (selected)	17.33	6.54	53.17	5.99	9.33	7.39	3.00	9.22	3.83	9.83
42449 (selected)	17.25	7.05	50.00	6.13	9.50	9.07	3.17	8.58	6.33	10.24
42440 (nonselected)	17.08	7.06	45.83	6.22	8.67	7.71	5.33	9.69	8.50	9.59
42465 (selected)	16.75	6.96	47.50	6.30	6.67	8.55	3.00	10.00	9.83	8.03
42452 (selected)	16.17	6.95	43.83	6.20	6.83	9.34	1.83	8.36	12.17	8.15
42445 (selected)	16.08	8.36	46.17	8.00	8.00	10.25	3.33	7.75	6.83	8.98
42450 (selected)	16.04	7.40	49.00	6.73	8.50	8.69	2.67	9.25	4.00	11.96
42460 (selected)	16.04	8.08	47.50	7.77	5.00	8.47	3.33	9.15	8.33	9.18
42474 (nonselected)	15.79	8.30	43.83	7.50	6.17	10.19	4.00	11.88	9.17	9.04
42441 (nonselected)	15.75	8.41	41.17	7.17	5.83	9.74	6.50	8.87	9.50	11.28
42448 (selected)	15.58	8.74	48.33	8.27	7.00	10.55	2.00	9.83	5.00	10.00
42469 (selected)	15.58	9.17	35.67	8.82	6.17	9.62	6.83	11.17	13.67	9.37
42436 (nonselected)	14.79	7.12	43.17	6.37	4.00	9.21	4.17	8.32	7.83	9.45
42458 (selected)	14.17	7.73	33.67	6.30	6.83	11.00	3.17	9.42	13.00	9.15
42435 (selected)	12.33	7.37	33.17	6.48	7.67	8.80	5.67	8.85	2.83	10.71
42475 (nonselected)	12.29	6.44	34.33	5.62	8.33	7.64	5.17	8.23	1.33	12.88
42475 (selected)	10.92	6.73	31.67	6.05	7.50	8.31	3.17	7.95	1.33	11.12
Experiment mean	19.53	7.60	49.70	6.75	9.62	8.64	6.29	9.46	12.50	9.29
Standard error of a difference between 2 means	4.32	.44	6.35	.54	2.08	.82	1.67	.83	2.45	.59

[1] See table 8 for W. B. McCallum's designations.
[2] All 1942 seed was nonselected.
[3] 1943 seed; none available for 1942.

were computed on the same basis as the means. The triple lattice design yielded an increase in precision over the randomized complete block of 8 percent for number of plants emerged and of 17 percent for time of emergence. This small increase in precision showed that very little would be gained by using adjusted means; hence, they were not computed. The means for the time of emergence for the whole-plot, or strain, total and the threshed, untreated seed are the average of 6-plot mean dates of emergence. There were sufficient plants in each to furnish a reliable plot mean. The mean dates of emergence for the 3 other seed treatments (unthreshed, untreated 1943 seed; unthreshed, treated 1943 seed; and unthreshed, treated 1942 seed) are weighted averages for the plants emerged in each plot. This procedure was followed because no plants emerged in some plots and in others the number of plants per plot was too small to give a reliable plot-mean date of emergence.

As a check, no sodium hypochlorite treatment or threshing was performed on one of the four seed samples for each entry. The second treatment consisted in threshing the seed 3 to 4 months prior to planting. No sodium hypochlorite or any other treatment was used on this sample. The threshing, which was performed by a seed-threshing machine involving the abrasive action of sandpaper, fanning, and a flotation process in acetone, resulted in the removal of bracts and sterile florets and most of the empty seeds (*1*). The third treatment was the usual sodium hypochlorite treatment (*1*) on unthreshed seed at about the same time as the date of threshing. These three treatments were applied to seed harvested in the fall of 1943. The emergence data on these strains were directly comparable for the seed treatments, because the seed collections were made from the replicated field test. Hence, any environmental influence due to location in the replicate on strains was controlled by replication. The fourth seed treatment involved nonselected seed harvested in 1942 from a nonreplicated planting. This seed was treated in February 1943 with sodium hypochlorite and stored at room temperature until the time of planting. Variations from the specific conditions for these seed treatments were studied by Benedict and Robinson (*1*) and will not be discussed here.

Emergence counts were made 4, 10, 13, 20, and 34 days after planting. The time of emergence is the average number of days to emergence after planting. Strains 42444, 42468, and 42478 were highest for percentage of emergence on the whole-plot basis. Strain 42475, both nonselected and selected, was at the bottom of the rankings with regard to percentage of emergence. The treatment, or split-plot, means are given opposite the whole-plot means. Highly significant differences existed among these strains within any of the treatments for percentage of emergence and for average number of days to emergence after planting.

Real differences existed between treatment means for percentage and time of emergence. The mean for emergence of threshed seed, 49.70 percent, was considerably higher than the mean percentage of emergence obtained for the other three seed treatments. The threshing process removed the unfilled seed, which necessarily remained in the unthreshed seed samples. This means that only the filled seed was planted for the threshed sample; consequently, a higher emergence resulted. Regardless of the cause, the percentage of emergence per amount of seed planted was greatly increased by using threshed seed. The 1942 unthreshed, treated seed treatment ranked second, the unthreshed, untreated seed treatment third, and the unthreshed, treated 1943 seed treatment last for percentage of emergence. Under the conditions of this test better results were obtained by not treating the 1943 seed than by treating with sodium hypochlorite. This particular sodium hypochlorite seed treatment had a deleterious effect in general on the percentage of emergence of the 1943 seed. In addition, the threshed seed emerged earlier than did the seed from the other treatments. The unthreshed, untreated seed was second for earliness of emergence and the treated seed was last. Apparently these sodium hypochlorite treatments retarded emergence in some manner.

Despite these differences, one of the most interesting results of this experiment was the significant strain $\times$ treatment interaction for both percentage and time of emergence. These guayule strains reacted differently to the four treatments applied. Therefore, no generalizations about the seed treatments, other than threshing, can be made for these guayule strains. Some strains emerged earlier and with a higher percentage under one treatment, whereas the reverse was true for other strains.

At the end of 5 weeks after planting there were no apparent differences in size of the seedlings from any of the four seed treatments. Naturally the plants emerging earliest would be the largest, but any difference between treatments was not apparent from an observational study of the material.

CONCLUSIONS

In light of the evidence presented, it is evident that a considerable amount of work in selection and hybridization must be done before a superior and uniform variety can be obtained from these strains. W. B. McCallum worked on them for a period of years to bring them up to their present standard, but now the work must be continued in order to produce a uniform variety with superior agronomic characteristics. From the evidence presented in the literature cited, isolation, either by bagging or distance, must be practiced in order to prevent contamination by foreign pollen. The selfed progeny of the superior individual-plant selections should be tested for the desired characteristics. The survivors of this test would be bulked, and the resulting progeny would be the new variety.

The culling operation as practiced by the nurseries growing guayule reduces the frequency of occurrence of the aberrant-type plants. This is not a permanent decrease, however, and the frequency of aberrants in the nursery plantings will be as high in the succeeding years as it was the previous year. Culling is a costly operation which can be eliminated by growing varieties that produce no aberrant or offtype plants. In addition, the yield of rubber per acre can be increased considerably by growing only normal plants. These facts are of considerable economic importance to the commercial guayule grower. Since the culling operation eliminates only part of the aberrants and is expensive besides, the only method of solving this problem is breeding. The guayule strains studied need to be improved before they should be grown commercially.

Reliable estimates of the relative yield of rubber from guayule strains can be obtained from plant spread and height measurements and rubber content of the branch samples. In this manner data on yield of rubber per plant may be obtained without destroying the plants. Plant spread alone gives a good estimate of the shrub weight, but it may be well to record height also as some strains have relatively large spread measurements but low height ones. These measurements are reliable for the time at which they were recorded. This was brought out by the relatively low relation between the plant-height measurements recorded in the greenhouse and in the field. Therefore, it would be inadvisable to record greenhouse measurements for the purpose of predicting field ones.

As an indication of the true relation between the logarithms of height and spread for strains of 1-year-old guayule, correlations of 0.903 from the 42 strains in the strain test and 0.898 from the 7 entries in the commercial-strain test were obtained. This close agreement from the 2 independent tests considerably strengthens the dependability of the relation obtained for height and spread.

SUMMARY

Data obtained on seed, seedling, and young-plant characters proved that considerable variability was present both within and among the 7 commercial strains and 35 of the more promising other strains of guayule developed by W. B. McCallum.

The seven commercial strains in the commercial-strain test differed significantly with respect to rubber content, shrub weight, and percentage of plants in each of the phenotypic classes: Normals, offtypes, slow growers, and aberrants. There were no significant differences among the totals of these strains for shrub weight, dry weight of leaves, and resin content. Strain 593 was recommended in preference to the other six commercial strains. It would be highly desirable to produce strains composed of normals, as this class was significantly higher in shrub weight and weight of rubber than were the offtypes, slow growers, and aberrants. Small differences among the phenotypic classes were obtained for rubber and resin contents.

Several plant characters were highly related. Height and spread were the best characters for the predictions of shrub weight; the relations were not linear but could be made so by a transformation to logarithms. Rubber content of the branch samples and of the plants was correlated to a fairly high degree, 0.668. The correlation between these two characters would have been higher if the size of the branch sample had been kept constant. It was higher when plot means rather than individual-plant data were used to determine the relation.

Significant differences existed among the individual-plant selections of the seven commercial strains for percentage of emergence, time of emergence, and frequency of occurrence of aberrant and offtype plants. Thus, the strains offer possibilities for improvement with regard to these three characters.

There were small differences in the percentages of plants emerging on a specified day after planting among the commercial strains. The

progeny of an offtype plant was similar to the offtype parent selection. The progeny of aberrants was mostly aberrant, but occasionally some normal plants occurred among their progeny.

Significant differences existed among the 42 strains (the 7 commercial strains and 35 of the other more promising of W. B. McCallum's strains) in the strain test for height, spread, the percentage of aberrant plants, date of first bloom, and percentage and time of emergence of seedlings grown from the 4 seed treatments and among the means and variances of height for aberrants and nonaberrants. The interaction of strains and seed treatments was significant statistically for both percentage and time of emergence. Apparently there were no significant differences with regard to the characters studied between the 54±- and the 72±-chromosome groups. The strains with the tallest nonaberrant plants on the average were not always associated with the tallest aberrant plants.

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U. S. GOVERNMENT PRINTING OFFICE: 1946

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